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The Effect of Latent Heat Release on Synoptic-to-Planetary Wave Interactions and Its Implication for Satellite Observations: Theoretical Modeling

INVESTIGATORS:

Principal Investigators:
Dr. Lee E. Branscome, Environmental Dynamics Research, Inc., 7338 155th Place North, Palm Beach Gardens, FL 33418, Ph. (407) 744-4889
Prof. Rainer Bleck, Univ. of Miami, Rosenstiel School of Marine and Atmospheric Science, 4600 Rickenbacker Causeway, Miami, FL 33149

Graduate Research Assistant:
Dr. Enda O'Brien, Univ. of Miami, Rosenstiel School of Marine and Atmospheric Science, 4600 Rickenbacker Causeway, Miami, FL 33149; Current Addr.: GFDL, Princeton, NJ 08540

SIGNIFICANT ACCOMPLISHMENTS IN THE PAST YEAR:

As an introduction, the project objectives are:

• Develop process models to investigate the interaction of planetary and synoptic-scale waves including the effects of latent heat release (precipitation), nonlinear dynamics, physical and boundary-layer processes, and large-scale topography

• Determine the importance of latent heat release for temporal variability and time-mean behavior of planetary and synoptic-scale waves

• Compare the model results with available observations of planetary and synoptic wave variability

• Assess the implications of the results for monitoring precipitation in oceanic storm tracks by satellite observing systems.

We have utilized two different models for this project:

a. A *two-level quasi-geostrophic* model to study intraseasonal variability, anomalous circulations and the seasonal cycle. This version explicitly resolves a few planetary and synoptic waves and examines the effect of latent heat release and topography on their interaction.

b. A *10-level, multi-wave primitive equation* model to validate the two-level Q-G model and examine effects of convection, surface processes, and spherical geometry. It explicitly resolves several planetary and synoptic waves and includes specific humidity (as a predicted variable), moist convection, and large-scale precipitation.

Work with the two-level quasi-geostrophic model was performed during the first two years of the contract and described in previous annual reports. The results have been presented in three refereed publications, coauthored by Drs. Branscome and O'Brien. In the past year we have concentrated on experiments with the multi-level primitive equation model. The dynamical part of that model is similar to the spectral model used by the National Meteorological Center for medium-range forecasts. The model includes parameterizations of large-scale condensation and moist convection. To test the validity of our results regarding the influence of convective precipitation, we can use either one of two different convective schemes in the model, a Kuo convective scheme or a modified Arakawa-Schubert scheme which includes down-drafts. By choosing one or the other scheme, we can evaluate the impact of the convective parameterization on the circulation.

In the past year we performed a variety of initial-value experiments with the primitive equation model. Using initial conditions typical of climatological winter conditions, we examined the behavior of synoptic and planetary waves growing in moist and dry environments. Surface conditions were representative of a zonally averaged ocean. We found that moist convection associated with baroclinic wave development was confined to the subtropics. Its contribution to

wave energetics was fairly small, although precipitation amounts were similar to the amounts from large-scale condensation. The result was similar for either choice of convective parameterization.

Precipitation in middle and high latitudes in our experiments was dominated by large-scale condensation. Large-scale condensation had its strongest effect on the short synoptic scales (zonal wavenumber 14) and accelerated the growth and decay of these waves. Latent heating did not directly enhance growth on the planetary scale (zonal wavenumber 4), but heating within the planetary scales modestly accelerated baroclinic growth of the synoptic scales. Also, some amplification of the planetary scales occurred when latent heat was released in the synoptic-scale waves.

The large-scale condensation was generated by mid-tropospheric upward motion in synoptic-scale waves and by cooling of moist air in low-level poleward flow over a comparatively cold sea surface. Thus, sensible heat exchanges between the model atmosphere and surface were important in determining the vertical distribution of condensation within the waves. However, latent heat release in the mid-troposphere made the most direct and obvious contribution to wave growth, whereas low-level condensation generated by surface processes did not enhance wave development. The vertical distribution of latent heat release and its impact on wave growth affects observational requirements for remote sensing, esp. over ocean areas. Our results suggest that mid-tropospheric latent heat release associated with synoptic-scale uplift is the most important contributor to wave dynamics and prediction and should receive special attention in observational studies.

In addition to the aforementioned experiments, we have also investigated the effect of climate change on water vapor transport and precipitation within mid-latitude waves. Climatic states generated by two different GCM's with current and doubled amounts of CO_2 were used as initial conditions for experiments with our primitive equation model. The model was integrated over the life cycle of a transient eddy. These short-term experiments allowed us to isolate the waves and their transport and precipitation processes from the many other feedbacks present in GCM climate experiments. By changing the initial conditions, surface processes, and model resolution, we were able to assess the impact of certain processes and modeling procedures on wave evolution, water vapor transport, and precipitation. Smaller meridional temperature gradients in a doubled CO_2 climate reduced eddy energy and sensible heat transport and shifted precipitation and eddy activity poleward. In contrast, the change in water vapor transport was comparatively small due to the compensating effect of higher specific humidity in the doubled CO_2 climate. These experiments indicate which aspects of eddy activity and transport will respond to climate change. Results of this research were presented at the June 1990 Chapman Conference on the Hydrological Aspects of Global Climate Change.

FOCUS OF CURRENT RESEARCH:

As the current project draws to a close in the next few months, we will perform some final experiments and prepare manuscripts which describe final results and conclusions. We are investigating more fully the contribution of moist convection to wave dynamics and interactions. We plan to perform some experiments in which the initial conditions are more conditionally unstable than the climatological zonal mean. Unstable conditions over the oceans are most likely to occur off the eastern coasts of the Asia and North America. These experiments will allow us to further compare precipitation processes and their effect on mid-latitude wave growth.

PLANS FOR NEXT YEAR:

For the next year we propose to investigate the interactions of clouds and mid-latitude transient eddies. Recent analyses of the earth's radiation budget (e.g., Ramanathan et al., 1989: Climate and the Earth's radiation budget. *Physics Today*, 42, 22-32; Ramanathan et al., 1989: Cloud-radiative forcing and climate: Insights from the Earth Radiation Budget Experiment. *Science*, 243, 57-63) have shown that the cloudy regions of extratropical storm tracks make a significant contribution to net global cooling by clouds and are likely to be a critical factor in the

global response to greenhouse enhancement. These storm tracks are dominated by synoptic-scale transient eddies, which are easily identified in satellite photos by their distinctive cloud patterns. Understanding the interactions of clouds and large-scale motions is essential for short-term weather prediction, since clouds and precipitation are key elements of daily weather. In addition to generating clouds, mid-latitude transient eddies accomplish a substantial portion of the total atmospheric transport of heat, moisture, and angular momentum. As a result, these eddies and associated cloud patterns constitute an important component of the general circulation.

We will evaluate various methods of cloud modeling and examine cloud behavior in the context of individual synoptic-scale eddies and long-term averages. We will also examine how physical processes such as radiation, moist convection, and surface fluxes control cloud-eddy interactions in context of a multi-level primitive equation model. One objective is an understanding of the response of eddies and their cloud systems to climate change. Our study of relevant physical processes will isolate certain interactions and thus, provide a clearer understanding of cloud feedbacks that occur in complex climate models, namely general circulation models. In addition, the results of our study will identify cloud processes that require more effective and accurate observation by remote sensing techniques. Our objectives will be accomplished through a variety of experiments with an idealized primitive-equation model, the same model described above but including cloud parameterizations and radiative transfer. The model will be configured to isolate feedbacks between clouds and mid-latitude transient eddies from other dynamical processes such as tropical waves and mid-latitude stationary waves.

Our three-year study will examine cloud-eddy interactions in the context of two types of experiments: (a) "life-cycle" experiments and (b) "climatic equilibrium" experiments. The life-cycle experiments are initial value problems which examine the effect of various physical processes, modeling procedures, or global climate changes on the life history of a single baroclinic eddy. A large number of these short-term (~20 day) integrations will be performed. Following various tests of modeling procedures in the life-cycle experiments, some climatic equilibrium experiments will be performed. The equilibrium experiments will primarily investigate the response of clouds and transient eddies to changes in external forcing, such as sea surface temperatures and insolation. The model will be integrated over long periods (several hundred days) to obtain an equilibrated or statistically steady state.

PUBLICATIONS:

1. Refereed papers by Branscome and O'Brien:

1988: Modes of variability in a low-order, two-level model. Tellus, 40A, 358-374.

1989: Minimal modeling of the atmospheric general circulation. Tellus, 41A, 292-307.

1990: The effect of large-scale topography on the circulation of low-order models. To appear in Oct 1 or 15 issue of J. Atmos. Sci.

2. Manuscripts in preparation by Branscome and co-workers:

a. Determination of frictional time scales for low-order models. To be submitted to J. Atmos. Sci.

b. The impact of global climate change on water vapor transport by transient eddies. To be submitted to J. Climate.

c. The effect of latent heat release on the interactions of nonlinear baroclinic waves. To be submitted to J. Atmos. Sci.